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10/511781
DT05 Rec'd PCT/PTO 15 OCT 2004

ARMOR SYSTEM

This invention claims the benefit of co-pending U.S. Provisional Application No. 60/373,755, entitled "Armor System", filed April 17, 2002, the entire disclosure of which is hereby incorporated by reference as if set forth in its entirety for all purposes.

Technical Field

The present invention is directed to armor systems and more particularly to an armor system that can be quickly and easily applied to an animate or inanimate body to be protected.

Background of the Invention

Many and various types of armor systems are known for shielding personnel, vehicles, and equipment from injury and/or damage from projectiles. Such armor systems are typically used in military environments to protect military personnel as well as military equipment such as, for example, aircraft, tanks, ships, and other vehicles. Armor systems are also used in law enforcement and other environments in which protection from armor piercing projectiles or other type of ballistic missiles is desired.

Armor can be made of various materials depending on what is to be protected and the level of threat or danger. For example, some armor is used in or with clothing to protect the body of military or law enforcement personnel. Such armor is typically a soft body armor of multiple plies of aramid and/or polyethylene cloth and is used with or incorporated into clothing such as, for example, body vests. Another type of armor is a rigid laminated fiberglass used to protect solid structures such as armored cars, bank

teller windows, and police structures. Yet another type of armor is special alloy steel, aluminum, or ceramic plate, which may be used in combination with other materials for military applications. Ceramic materials in various forms are also used as armor.

In some applications the armor is incorporated into the structure that is to be protected. Such applications may include military vehicles, armored vehicles, and structures for cashiers or security personnel. Since the armor must be incorporated into these structures it is not possible to quickly and easily provide armor for protection for structures or bodies that do not have "built-in" armor.

Some armor systems do employ some means of attaching the armor system to the body or structure to be protected. For example, some armor systems may be attached to a body or structure with fasteners such as bolts or screws. Other armor systems may utilize glue to adhere the armor to the body. However, this usually requires the application of a liquid glue to the armor and/or the body to which the armor is being attached. This increases the time and cost of applying the armor. Furthermore, such glues are costly, inconvenient to apply, and may be hazardous due to fumes or other hazardous chemicals involved. Also, such liquid glues require storage, which further increases costs especially if a special storage facility is required.

Some armor systems use a magnet to attach the armor to a body. However, magnetic armor systems are limited in use to metallic bodies and structures and are not suitable for some applications.

Another problem encountered with prior art armor systems is weight. Some armor systems employ thick steel plates. However, the weight of the steel plates makes such

armor systems undesirable. Furthermore, with the development of armor piercing projectiles the thickness of the steel plates used in armor systems has increased which further increases the cost and weight of the armor system and decreases its ability to conform to some surfaces.

In order to provide a more lightweight armor, some systems have employed forms of ceramic material that have had some effect against projectiles. For example, ceramic tiles have been used to dissipate the kinetic energy of projectiles. In some armor systems, the ceramic tiles are arranged in a specific pattern and attached to a backing material such as nylon to form a ceramic tile sheet. The ceramic tiles may have a variety of shapes such as, for example, a square or octagonal shape. However, upon impact the ceramic tiles shatter creating voids and dangerous fragments. In order to be effective, the ceramic tiles must be arranged with a minimum spacing between them. The spacing provides room for the ceramic tiles to expand as they crack and/or shatter to absorb the energy of the projectile. This precise spacing of the ceramic tiles is time consuming and adds to the cost of manufacture of the armor system. Furthermore, if the spacing is not right the armor system may not be effective. In other armor systems, single or multiple ceramic tiles may be employed at one or more locations within the armor system. However, as with the ceramic sheets, the ceramic tiles may shatter creating dangerous fragments.

One solution to the problem of the creation of ceramic fragments is to combine the ceramic sheet or sheets with thick sheets or layers of glass or plastic cloth to absorb the

shattered ceramic pieces. Such cloth is typically a woven ballistic cloth, such as Kevlar® and Spectra® film.

Even though such armor systems have proven effective the weight is still more than is desirable. Additionally, the cost of the ceramic tiles is expensive.

Another problem encountered with prior armor systems is their inability to conform to some surfaces. It is desirable that the armor system be flexible so that it can conform to a variety of bodies to be protected. For example, such armor systems are desirable for use as body suits for military or law enforcement personnel as well as for vehicles and other objects. It is preferable that the armor system be adaptable to any of such uses.

Another problem with prior armor systems is that any projectiles that penetrate the armor system create voids in the armor system leaving the body to be protected vulnerable to damage from additional projectiles. Additionally, such voids subject the body to be protected from other types of damage. For example, in marine environments a void created by a projectile may allow water to penetrate and damage the body to be protected. Such voids may also allow nuclear, chemical, or biological agents to penetrate the through the armor system.

Examples of prior art ceramic armor systems include U.S. Patent Nos. 3,924,038, 4,911,061, and 5,705,764, the subject matter of which is incorporated herein by reference.

However, none of the prior art discloses an armor system that can be quickly and easily applied to a body or structure.

Summary of the Invention

The foregoing problems are overcome and other advantages are provided by an armor system that can be quickly and easily applied to a body to be protected and that provides a high degree of protection from a projectile.

In certain embodiments, the present invention provides an armor system that is flexible and can conform to a variety of shapes and surfaces.

The present invention provides an armor system that can be quickly and easily applied to a body or object to be protected. The armor system preferably includes one or more armor units that include a pressure sensitive adhesive such as, for example, a "peel and stick" adhesive to adhere the armor system to the body to be protected. The pressure sensitive adhesive adheres to most surfaces and adheres extremely well to high-energy surfaces such metal, wood, concrete, glass, or other smooth surfaces. The pressure sensitive adhesive can be formed on either the backside of the armor system for application to an outer surface of the body or structure or can be formed on the front side of the armor system for application to an inner surface of the body or structure. Alternatively, the pressure sensitive adhesive can be formed on both the front and back side of the armor system for an even wider range of applications.

The present invention may also provide an armor system that includes layers of different protective materials that can be arranged in various combinations depending on factors such as, for example, the level of threat, cost, weight, and environment of use.

The armor units may include an outer case that can be filled with layers of different protective materials either alone or in various combinations depending on

factors such as threat level, weight, cost, and conformability. One of the preferred layers may be a ceramic layer that may in various forms of ceramic including ceramic plates, sheets of ceramic tiles, or loose ceramic spheres or balls. Other layers of protective materials may include multiple layers of woven or unidirectional cloth and a steel mesh layer.

In one possible embodiment, the ceramic layer includes loose ceramic filler material that randomly fills the outer case. The ceramic filler material is preferably in the form of ceramic balls or spheres but may be in any desired shape. The ceramic balls may have substantially uniform diameters or may have various diameters. Additionally, the ceramic filler material may be encapsulated within a resin matrix instead being a loose fill. The ceramic balls are combined with at least one layer of steel mesh and plural layers of woven ballistic cloth.

In another possible embodiment, the armor unit includes a self-healing layer in which the void left by the projectile is filled and the armor unit is sealed to prevent the protective materials from spilling out of the outer case. In one arrangement of the self-healing embodiment, the armor unit includes plural bags of loose ceramic fill combined with a tensioned steel spring and a layer of foam packets each of which include foam that expands and hardens when exposed to air. When the armor unit is pierced by a projectile the foam expands into the void left by the projectile and hardens preventing the loose ceramic fill from spilling out of the outer case. In another embodiment, the armor unit includes a layer of tubes filled with ceramic material located adjacent a layer of foam packets. Each tube includes springs located at each end to place the ceramic material

under compression and explosive end caps at each end. When the tube is shattered by a projectile the ceramic material is forced by the springs into the void created by the projectile. Since the foam packets is the first layer to encounter the projectile at least one of the foam packets is ruptured by the projectile so that the foam is exposed to air and expands hardens to prevent the ceramic material from spilling out of the outer case.

The self-healing armor unit may include various layers of strengthening material for added protection. A high strength woven adhesive tape material is provided that can be adhered to one or both sides of one of the protective layers such as, for example, one or more of the layers of ceramic or tensioned steel spring. Another strengthening material that may be bonded to one of the layers may be a high strength metal layer.

The present invention further provides a lighter weight ceramic layer that includes perforated ceramic tiles. Each ceramic tile includes plural holes that reduce the weight of the ceramic tile but allows the ceramic tile to retain its strength properties. In one embodiment, the holes are filled with a polymer material capable of bonding a high strength protective material, such as, for example, a metal plate to the ceramic tile.

The present invention provides an armor system that is lightweight and that can be quickly and easily applied to many bodies and vehicles. The armor system is preferably flexible so that it can be easily applied to either flat or non-flat areas on military or law enforcement personnel, vehicles, critical systems such as, for example, oil and gas pipelines, and other objects where protection from weapons or explosives are required. One example of such use is the application of the flexible armor system to surfaces of helicopter fuselages to protect pilots and critical flight systems.

The present invention provides a light flexible armor that easily conforms to different surfaces and shapes, that adheres aggressively to a variety of curved or flat surfaces, and that is capable of stopping numerous types of threats.

The foregoing embodiments and features are for illustrative purposes and are not intended to be limiting, persons skilled in the art being capable of appreciating other embodiments from the scope and spirit of the foregoing teachings.

Brief Description of the Drawings

Figure 1 is a perspective view of one embodiment of an armor system unit with multiple layers of protective material.

Figure 2 is a partial view of a hexagonal ceramic tiles.

Figure 3 is a partial view of a layer of ceramic tile squares.

Figure 4 is a partial view of a layer of perforated ceramic tiles.

Figure 5 is a partial view of a layer of triangular shaped ceramic tiles.

Figure 6 a perspective view of another embodiment of an armor system unit with a loose fill ceramic layer.

Figure 7 is a partial perspective view showing a self-healing armor unit with an expandable foam layer.

Figure 8 is a partial view of a tensioned steel spring.

Figure 9 is a view of a punctured expandable foam packet.

Figure 10 is a view of a single layer of expandable foam packets.

Figure 11 is a view of a double layer of expandable foam packets.

Figure 12 is a view showing a self-healing armor unit with ceramic filled tubes.

Figure 13 is a view of a ceramic filled tube.

Figure 14 is a view of a ceramic filled tube with one end shown in an exploded condition.

Figure 15 is a view of a ceramic filled tube shown ruptured at a center portion.

Figure 16 is a view of another embodiment of a self-healing armor unit.

Figure 17 is a view of another embodiment of a self-healing armor unit with ceramic filled tubes positioned with their ends facing outwardly.

Figure 18 is a view of an armor unit with a steel spring layer strengthened with a high strength woven adhesive tape.

Figure 19 is a view of a protective layer of ceramic filled tubes and tensioned steel spring strengthened with a high strength woven adhesive tape.

Figure 20 is a view of a protective layer of hexagonal ceramic tiles strengthened with a high strength woven adhesive tape.

Figure 21 is a view of a protective layer of square ceramic tiles strengthened with a high strength woven adhesive tape.

Figure 22 is a view of a protective layer of perforated ceramic tiles strengthened with a high strength woven adhesive tape.

Figure 23 is a view of a protective layer of ceramic and high strength metal.

Figure 24 is a view of a perforated ceramic tile with a polymer fill in the holes.

Figure 25 is a view of a protective layer of aluminum, ceramic, and glass composite.

Detailed Description

In certain embodiments, the armor system of the present invention provides an armor that can be quickly and easily applied to a body to be protected and adapted to a variety of situations depending on the level of threat and the level of protection needed. The armor system may include plural armor units that include an outer case that can be filled with a variety of protective materials either alone or in combination with other protective materials. The type and combination of materials that are enclosed within the outer case depend on several factors such as, for example, the level of threat and protection that is needed against the threat, the weight of the armor system, the need for the armor system to conform to the body to which it is to protects, and the cost of the armor system.

Figure 1 shows an armor unit 10, one or more of which make up the armor system of the present invention. Although only one armor unit 10 is shown it is understood that many more armor units 10 may be used depending on the application or body to be protected. For example, the armor system may be used in a wide variety of applications such as, for example, to protect people, cars, buildings, or naval craft. The number of armor units 10 used depends on the size of the area to be protected. Each armor unit 10 includes an outer case 12 that encloses one or more protective materials 14. Outer case 12 may be formed in any suitable manner. However, as shown in Fig. 1, outer case 10 is preferably made of first and second sheets of material 16 and 18 located adjacent each other with their outer edges aligned and stitched or sewn together preferably with a ballistic thread along a seam 20 to form sidewalls 22. Although the outer edges of first

and second sheets 16 and 18 are shown as being sewn they could be secured in any other suitable manner. First sheet 16 comprises a front side 24 that faces an incoming bullet, missile, or other projectile. Second sheet 18 comprises a backside 26 that lies adjacent to the body to be protected. Figure 1 shows one side of outer case 12 as being open but this is merely for illustrative purposes to reveal protective material layers 14. Normally, all edges of outer case 12 are sewn or stitched closed. Further, outer case 12 can be made of any material suitable for containing protective material layers 14 but is preferably made of a ballistic cloth of woven fibers such as, for example, glass rovings or fibers. Plastic fibers such as, for example, polyethylene plastic may also be used. Examples of suitable plastic fiber material of woven or unidirectional ballistic fibers such as, for example, Kevlar™, manufactured by Hexcel Schwebel, of Anderson, SC and Dyneema™, manufactured by DSM High Performance Fibers, of Greenville, NC.

In order to quickly and easily apply armor unit 10 to a body or structure outer case 10 includes a pre-applied securing layer on any portion thereof such as, for example, on one or both sides of outer case 10. The securing layer may be either a heat sensitive or a pressure sensitive securing layer. One example of a pre-applied pressure sensitive securing layer is Velcro™ or any other securing layer that can mate with a complementary surface on the body to be protected. Preferably, the securing layer is a pre-applied adhesive on a side allowing that side to be applied to the body or structure. The pressure sensitive adhesive is preferably a "peel and stick" type of adhesive in which a release liner is peeled away to expose the adhesive, which is then applied to a surface of the body or structure to be protected. As shown in Fig. 1, armor unit 10 includes a "peel

and stick" adhesive layer 28 attached to backside 26 so that armor unit 10 can be quickly and easily adhered to a body to be protected. Adhesive layer 28 includes a thin film with a pressure sensitive adhesive bonded thereto. Any type of very strong pressure sensitive adhesive may be used. One example of such a pressure sensitive adhesive is Scotchcal ™ Film 3662-10 manufactured by 3M Corporation of Minneapolis, Minnesota. A release liner 30 covers the adhesive so that it maintains its tack until it is ready for use. Adhesive layer 28 is bonded to outer case 12 with a strong flexible adhesive bonding layer 32 such as, for example, a two-part liquid bonding agent such as, for example, a polyurethane resin. Examples of such adhesive resin are Z-7050 polyurethane compound and Z-8O5O-10 polyurethane compound manufactured by Development Associates, Inc. of North Kingston, RI. After bonding layer 32 has been applied to outer case 12, adhesive layer 28 is attached thereto and pressure, preferably about 100 lbs./ft.^{2}, is applied for a period of time to allow adhesive layer 28 to bond to outer case 12. Outer case 12 is preferably porous so that the liquid bonding agent seeps through outer case 12 and bonds with the adjacent layer of protective material.

Figure 1 shows adhesive layer 28 on backside 26 so that armor unit 10 can be attached to an outer surface of a body to be protected. However, adhesive layer 28 may be attached to front side 24 so that it can be adhered to an inner surface of a body to be protected. Alternatively, an adhesive layer 28 may be adhered to both front side 24 and backside 26 for an even wider range of application. However, it should be understood that regardless of whether armor unit 10 is adhered to an outer surface or an inner surface of a body to be protected the layers of protective materials 14 are arranged so that a

particular desired layer of protective material is the first to encounter a bullet or projectile. When armor unit 10 is ready to be adhered to a body release liner 30 is peeled away to expose adhesive layer 28, which is then applied to the body.

Referring to Fig. 1, outer case 12 encloses a combination of protective materials 14 some of which may be used alone or in combination depending on certain factors discussed above such as, for example, the threat level and the amount of protection needed against the threat. The armor system shown in Fig. 1 is merely an example of types and combinations of protective materials 14 enclosed within the outer case 12. In the embodiment shown in Fig. 1, outer case 12 of armor unit 10 encloses three layers of protective material. In this example, an initial impact layer is located directly adjacent front side 24 to absorb the energy of the projectile. The initial impact layer is shown to include multiple layers 34 of woven or unidirectional ballistic cloth intended to be the first protective layer to encounter a projectile to absorb the energy of the projectile. Cloth layers 34 may be of the same material as outer case 12 which may be woven glass fibers or woven plastic fibers such as, for example, Spectra™, manufactured by Hexcel Schwebel, of Anderson, SC, Kevlar™, or Dyneema™. The embodiment shown in Fig. 1 is shown using fifty layers of 903-Spectra™ woven fabric. If it is important to have a very lightweight armor, the initial impact layer may comprise unidirectional fiber cloth such as, for example, Spectra Shield™ film manufactured by Hexce! Schwebel, of Anderson, SC. The unidirectional fiber layer may be used with or without other protective layers such as, for example, ceramic layers as discussed below. In another embodiment, the initial impact layer can be a layer of hard material such as, for example,

ceramic 38 discussed below to absorb the energy of the projectile and to deform and/or break it up. This is preferable when protecting against threats from high velocity projectiles.

An optional protective second layer is located adjacent the initial impact layer to further absorb the energy of the projectile. The optional protective second layer is shown to include a steel mesh layer 36 which may be used to further break up and absorb the kinetic energy of a projectile. The most effective location for steel mesh layer 36 is directly behind cloth layers 34. However, steel mesh layer 36 could be placed in other locations. In one example, steel mesh layer 36 comprises 25 x 110 woven wire mesh of .015 in. (mesh thickness) x .0105 in. (wire diameter) formed in a Plain Dutch weave. A third energy-absorbing layer of firm or hard material is provided to further absorb the energy of the projectile and to break it up. The energy-absorbing layer preferably includes a ceramic 38. The ceramic material used in ceramic layer 38 may be any type of ceramic such as, for example, an aluminum oxide, a silicon carbide, or a boron carbide. For example, the ceramic material may have an alumina content of between about 85 to about 99 percent to provide an aggregate of extreme hardness having a great resistance to fracture because of its very high compressive strength. For example, suitable ceramic materials are available from CoorsTek of Golden, CO or other manufacturers such as, for example, Fujimi America, Inc. of Portland, OR. In addition, the energy-absorbing layer may be other hard materials such as, for example, polymer compositions including a woven high-density polyethylene, glass or vitreous-like materials, metals including

tungsten wire or mesh-based elements, and other substances with similar impact-resistant and/or energy-absorbing properties.

The energy-absorbing layer may be in any number of forms and may include, for example, at least one and preferably a plurality of single ceramic plates 40 enclosed within the outer case 12 and having a thickness sufficient to provide protection depending on need.

An alternative energy-absorbing layer may include, for example, one or more multi-tile sheets 42 (Figs. 2-5) composed of plural ceramic tiles attached to a glass fiber cloth base sheet 43 by a resin material. The ceramic tiles may be formed in a variety of shapes. For example, as seen in Figs. 2-5, sheet 42 may include hexagonal-shaped ceramic tiles 44 (Fig. 2) such as, for example, a one-quarter inch ceramic hex mesh armor of the type manufactured by CoorsTek of Golden, CO, or rectangular-shaped tiles 46 (Fig. 3). The flexibility of hexagonal-shaped ceramic tiles 44 make them particularly useful for protecting vehicles. Rectangular-shaped tiles 46 are particularly useful for protecting buildings. When weight is a concern and/or extra strength is needed sheet 42 may include perforated tiles 48 (Fig. 4). Perforated tiles 48 include holes 50 drilled or otherwise formed therein at spaced intervals. For example, holes 50 may have a diameter of preferably no greater than about 3/16 inches (or between 4 and 5 mm) spaced about 1 cm center-to-center. Perforated tiles 48 are lighter in weight than solid ceramic tiles and provide a stronger tile that is less prone to shattering upon impact. Triangular shaped tiles 51 are shown in Figure 5.

The ceramic tiles shown in Figs. 2-5 may be arranged in an abutting relationship or in a spaced relationship. For example, the ceramic tiles may be spaced between 0.03 to 0.05 inches on all sides. The spacing between the ceramic tiles typically depends upon the selected tile thickness for a particular application. The spacing of between 0.03 to 0.05 inches gives the ceramic tile sheet an inherent tendency to give or recoil somewhat under impact. Triangular shaped tiles 51 have significant flexibility and are preferably adapted for use with human body armor.

The ceramic tiles or other energy-absorbing tiles or elements may have different dimensions depending on the application. For example, ceramic tiles for use with body armor preferably have a thickness of about 3.1750 mm in order to provide flexibility. Ceramic tiles with greater dimensions may be employed when the threat level is higher and/or flexibility is less of an issue. An example of ceramic tile dimensions for use in a higher threat level include ceramic tiles having a width of about 50 mm, a length of about 50 mm, and a thickness of between about 3 and 20 mm. Alternatively, ceramic tiles may have a width of about 100 mm, a length of about 150 mm, and a thickness of between 4 and 50 mm may be used for even higher threat level. For greater protection, ceramic tiles may have a width of about 114 mm, a length of about 228 mm, and a thickness of between about 6 and 50 mm. These represent examples of ceramic tile dimensions and the invention is not limited to these specific examples. The brittle nature of the ceramic tiles may cause them to shatter upon contact with projectiles or flying fragments. This shattering of the ceramic tiles at least partially absorbs the kinetic energy of the projectile

and also fragments the incoming projectile. Additionally, cloth layers 34 help absorb the impact of the projectile and also catch or contain ceramic pieces as they shatter due to the impact.

Flexibility for a layer can be varied by sizing energy absorbing materials into small tiles which can be of various shapes and sizes as seen most clearly in Figs. 2-5.

In another embodiment seen in Fig. 6, the energy-absorbing layer includes loose discrete elements. The discrete elements may be of any suitable material and any size and shape. The discrete elements are shown in Fig. 6 as being in the form of a plurality of ceramic balls or spheres 52. Ceramic balls 52 may have a uniform diameter or the diameters may vary. In one example, ceramic balls 52 have a diameter ranging from between 5 mm to 20 mm. Preferably, ceramic balls 52 are loose and are not arranged in any particular orientation but randomly fill outer case 12 to be as dense as possible. However, ceramic balls 52 may alternatively be embedded in a matrix of, for example, polyurethane. Armor units 10 having loose ceramic fill are particularly useful for protecting buildings.

A self-healing armor unit 11 is shown in Fig. 7 in which outer case 12 includes an energy-absorbing layer shown as individual encasements 54 filled with loose discrete ceramic elements such as, for example, ceramic balls 52 discussed above. Encasements 54 are preferably made of the same material as outer case 12 and can be of any suitable size. A tensioned spring 56 (Fig. 8) such as, for example, a high carbon steel spring, is located adjacent encasements 54 and provides a force tending to keep or hold encasements 54 in place and provides a further protective layer. However, spring 56 is

brittle and will shatter upon impact by a projectile allowing the projectile to possibly rupture an encasement 54. In order to prevent ceramic balls 52 from spilling out of outer case 12 after a projectile has penetrated outer case 12 a self-healing initial impact layer is provided in the form of a layer of expansion packets 58 filled with an expandable agent such as, for example, an expandable foam. One suitable type of expandable foam is Thixo-Foam, manufactured by Todol Products of Natick, MA. Another suitable expandable foam is Liquid Foam, manufactured by U.S. Composites of West Palm Beach, FL. The layer of expansion packets 58 is located immediately adjacent front side 24 so that expansion packets 58 are the first layer to encounter a projectile. Expansion packets 58 may be suitably sized and shaped to be, for example, either 2 in. by 2 in. square packets or 4 in. by 4 in. square packets and are filled with a foam that, when exposed to air, expands and hardens forming a foam barrier 59 as seen in Fig. 9.

Expansion packets 58 may be provided in a single layer (Fig. 10) or a double layer (Fig. 11). In one possible embodiment, an expansion packet 58 is punctured by a projectile so that air contacts the foam causing it to expand and fill the void left by the projectile. Hardened foam barrier 59 prevents ceramic balls 52 from spilling out of outer case 12 should the projectile pierce spring 56 and bags 54. Preferably, the foam is dyed to be the same color as outer case 12 to camouflage any penetration by a projectile. Armor unit 11 may include a securing layer on both sides of outer case 12 and is shown with a "peel and stick" adhesive layer 28 with release liner 30 is applied to both front side 24 and backside 26 of armor unit 11. However, adhesive layer 28 may be applied only to

either front side 24 or backside 26 depending on need. The self-healing armor unit 11 is particularly useful in marine environments because the expanded and hardened foam fills and seals punctures forming a substantially airtight barrier. Other useful applications for self-healing armor unit 11 is in nuclear, biological, or chemical warfare environments because the expanded and hardened foam could prevent such hazardous agents from seeping into, for example, a vehicle.

Figure 12 shows another embodiment of a self-healing armor unit 11 in which outer case 12 includes a securing layer on at least one outer side shown here as an adhesive layer 28 with release liner 30. Outer case 12 contains plural energy-absorbing layers shown here as multiple layers ballistic cloth 34 and ceramic layer 38 which may include any of the ceramic tiles discussed above. Outer case 12 further includes a tensioned energy layer including plural discrete elements under tension that are released upon impact to repopulate the void created by the projectile. The tensioned energy layer is shown to include a layer of ceramic filled glass or plastic tubes 60. As seen in Fig. 13, each tube 60 is filled with a plurality of ceramic balls 52 held under compression by springs 62 located at each end thereof' When a projectile ruptures a tube 60, springs 62 force balls 52 into the void formed by the projectile. Alternatively, each tube 60 may include an end cap 64 located at each end thereof that releases energy upon impact by a projectile to instantaneously propel ceramic balls 52 into the void created by the projectile. End caps 64 may be in any suitable form such as, for example, compressed gas or an explosive. In the embodiment shown in Fig. 12, each tube 60 includes both springs 62 and end caps 64. End caps 64 are shown in Fig. 12 as an explosive end cap

similar to percussive caps found in bullets and which explode upon impact by a projectile. Figure 14 shows tube 60 in an exploded condition after one of end caps 64 having been struck by a projectile. After end cap 64 explodes, the force of the explosion and the force of one of springs 62 forces ceramic balls 52 out of tube 60 to fill the void left by the projectile. Figure 15 shows tube 60 in an exploded condition after having been struck in the center by a projectile. In this example, both springs 62 force ceramic balls 52 out to fill the void left by the projectile. As further seen in Fig. 12, a layer of expansion packets 58 is located immediately adjacent the layer of tubes 60 and is the initial impact layer that encounters a projectile to prevent ceramic balls 52 from spilling out from outer case 12.

Figure 16 shows an alternative arrangement of protective layers including an energy-absorbing layer of plural encasements 54 with discrete energy-absorbing elements such as, for example, ceramic balls 52, tensioned spring 56, energy tensioned layer such as, for example, ceramic filled tubes 60, and an initial impact layer of expansion packets 58. This alternative arrangement provides a lighter weight armor unit 11.

In order to counter the force of an incoming projectile, self-healing armor unit 11 shown in Fig. 17 includes an energy-absorbing layer such as, for example, ceramic 38 and a tensioned energy layer of, for example, tubes 60 that are oriented with their lengths extending between ceramic layer 38 and front side 24 of outer case 12. When a tube 60 is struck by a projectile ceramic balls 52 located within tubes 60 are forced outward in a direction substantially against the direction of force of the projectile. An initial impact

layer of expansion packets 58 is located immediately adjacent tubes 60 to prevent ceramic balls 52 from spilling out of outer case 12.

Figure 18 shows a lighter weight armor unit 13 that includes an energy-absorbing layer such as, for example, encasements 54 of ceramic balls 52 and an optional protective second layer such as, for example, tensioned spring 56. In this embodiment, tensioned spring 56 is strengthened by a high strength woven adhesive tape 66. One example of such high strength tape 66 is 3M 3662-10 Scothcal™, manufactured by 3M Corporation, in St. Paul, MN. High strength tape 66 is shown applied to both sides of tensioned spring 56. However, high strength tape 66 may be applied to only one side of tensioned spring 56. This embodiment is advantageous for use in the protection of buildings as it is light-weight and easily conformable to various surfaces. Additionally, high strength tape 66 provides a higher level of protection.

Figure 19 shows an alternative protective layer that may be included in outer case 12 in which the tensioned energy layer of, for example, ceramic filled tubes 60 and tensioned spring 56 are located adjacent each other with high strength tape 66 applied to both sides. This protective layer can be placed in any desired position within outer case 12 and combined with any of the protective layers previously discussed.

Figures 20-22 shown various examples of an energy-absorbing layer with high strength tape 66 applied to each side thereof. For example, multi-tile sheets 42 may include hex tiles 44 (Fig. 20), solid rectangular tiles 46 (Fig. 21), or perforated tiles 48 (Fig. 22). High strength tape 64 provides a higher degree of protection from a projectile and additionally prevents shattering of the ceramic tiles. The multi-tile sheets 42 with

high strength tape 66 may be used in any of the previously discussed arrangement of protective materials either as the only ceramic layer or combined with other ceramic or non-ceramic layers.

Figure 23 shows an alternative protective layer in which a high strength metal layer 68 such as, for example, titanium is bonded to an energy-absorbing layer such as, for example, ceramic 38. Any type of high strength bonding agent may be used to adhere metal layer 68 to ceramic layer 38. Examples include epoxy resin, cement, or dental adhesives. In addition to providing extra protection, metal layer 68 helps prevent shattering of ceramic layer 38.

Figure 24 shows an embodiment of perforated tile 70 having a fill 72 in each hole 74. Fill 72 may be a polymer such as, for example, the Z-7050 polyurethane compound discussed above. Fill 72 flows just past the surfaces of tile 70 and serves as a bonding agent to adhere strengthening materials such as, for example, metal plate 68.

Figure 25 shows another protective energy-absorbing layer that may be included in outer case 12. This energy-absorbing layer is shown to include three layers of material bonded together. Specifically, a layer of aluminum 80 is bonded to a layer of ceramic 82, which is then bonded to a layer of glass or plastic composite material 84 such as, for example, a ballistic panel manufactured by Oak Ridge Plastics, of Ripon, WI. This bonded protective layer is particularly useful in marine environments and may be used in place of protective layers that include woven materials that degrade in water or very wet environments.

It should be understood that the foregoing description is only illustrative of the invention. Various alternatives and modifications can be devised by those skilled in the art without departing from the invention. Accordingly, the present invention is intended to embrace all such alternatives, modifications, and variances which fall within the scope of the appended claims.